IMPLEMENTATION OF MIDNIGHT BLACKBODY CALIBRATION CORRECTION (MBCC)

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I INTRODUCTION

At certain times of the year, the magnitudes of the computed calibration slopes for the GOES Imagers' infrared channels exhibit anomalous dips during the approximately eight hours centered on satellite midnight. The amplitudes of the dips usually decrease with increasing wavelength. For GOES-8, the anomalous dips occurred during the months between April and October. However, GOES-10 experiences this phenomenon all year round. GOES-12, which became operational April 1, 2003, has so far exhibited the effect all the time, but we do not know whether it will continue year-round. (Data collected during post-launch checkout in the fall of 2001 also exhibited the effect.) A complete discussion of this effect and an earlier version of the algorithm to correct for it is contained in Johnson and Weinreb (1996).

We believe these dips are errors in the slope computations, for two reasons. First, studies by the University of Wisconsin correlate the dip with errors--of the order of 1 K-- in the measurement of ocean surface temperatures. We also have seen other reports, both informal and in the scientific literature, of anomalous observations around midnight. In addition, such errors in computed slopes were predicted in 1988 by ITT (Annable, 1988), the Imagers' manufacturer. By analysis of the instrument's design, Annable showed that radiation from the Image Navigation and Registration (INR) sunshields in the imager's scan cavity, which can reach temperatures up to 350K, could be reflected by the imager's internal blackbody to its detectors during the blackbody sequence. The extraneous radiation from the sunshields would cause slope errors with characteristics similar to the dips we see in orbit.

The midnight blackbody calibration correction (MBCC) algorithm, a modification of the algorithm presented in Johnson and Weinreb (1996), will be implemented in processing in the Sensor Processing System (SPS) at the Wallops Command and Data Acquisition Station (WCDAS) to correct the calibration slopes. A description of the MBCC algorithm follows. Shown in Fig. 1 is an example of how the MBCC algorithm improves the calibration by reducing the magnitudes of the dips around midnight.

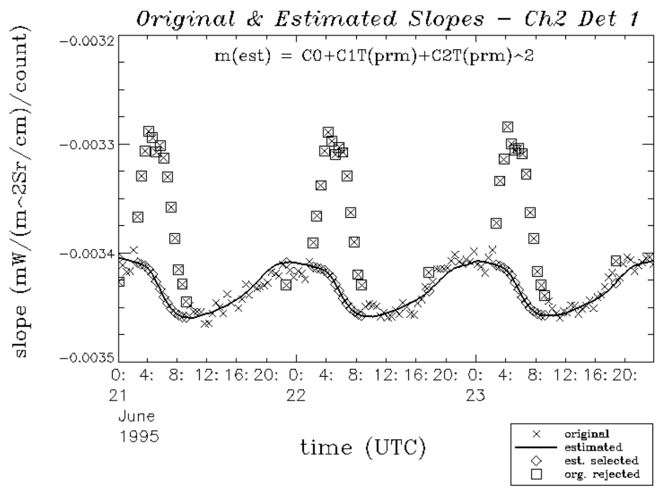

Fig. 1. Original slopes, and slopes corrected by MBCC

II MIDNIGHT ALGORITHM IN THE SPS AT WCDAS

A. Overview

The GOES ground processing system uses Imager observations of space and its internal blackbody to determine the calibration slope, represented by the coefficient m in the calibration equation,

$$R = qX^2 + mX + b, \tag{1}$$

where R is radiance, q the coefficient of the quadratic term (determined in laboratory testing before launch), X the output of the Imager channel in 10-bit digital counts, and b the calibration intercept. The blackbody looks and their associated calibrations occur once every 30 minutes. In actual operations, the calibration equation contains additional terms to account for the polarization-induced change of the scan mirror's reflectivity with east-west scan angle. Furthermore, the slopes are usually filtered to reduced noise. The filtering is done via a two-hour running average of slopes from the current day and several previous days. The filtered slopes are called the "mode-3" slopes. (The original, unfiltered slopes are "mode 1"). For details on the calibration of the Imager, see Weinreb et al. (1997).

In the MBCC algorithm, most steps will involve the responsivity rather than the calibration slope. The responsivity r is a simple function of the slope m, i.e.,

$$r = (m + 2qX_{bb})^{-1}, \tag{2}$$

where X_{bb} is the value of the instrument output (in counts) at the blackbody view, which was originally used in the computation of m. Because of the relationship expressed in Eq. (2), the slope and the responsivity are equivalent, i.e., whenever we know one, we know the other.

At each blackbody sequence, the SPS will perform a quadratic regression to generate the polynomial coefficients relating the responsivity to the temperature of one of the Imager's optical components, using a dependent sample of optics temperatures and slopes (and responsivities calculated from them) collected over previous days. The dependent sample will exclude the data from the hours around midnight, since they may be erroneous. The SPS will then compare the responsivity associated with the slope calculated by the normal techniques (the "original" responsivity) with a responsivity estimated from the optics temperatures. If the original and estimated responsivities are in agreement, the original slope will be deemed to be correct, and the SPS will use it in further processing. If the two responsivities disagree, it is assumed that radiation from the INR sunshields corrupted the original slope computation, so the SPS will compute a slope from the estimated responsivity and use that in further processing.

When the MBCC algorithm becomes operational, it will be used for all the Imager IR detectors at each blackbody sequence, and it will be used all the time, not only near midnight. As long as the responsivities associated with the original slopes are reasonable, the original slopes will be accepted and applied to transform the detector pixel outputs to radiances, as in that case the original responsivities will agree with the estimates. On the other hand, should the midnight effect, or a random noise spike at any time of day, corrupt a computed slope, the SPS will replace it with a slope computed from the estimated responsivity, which should be closer to the truth. In that way, the compensating algorithm will be beneficial even during the day, when the slope-dips are not expected to occur.

B. Details

1. Regression

The regression will generate the coefficients a_i, from which an estimate of the responsivity r^{est} will be obtained as a quadratic in the temperature T of one of the instrument's optics components:

$$r^{est} = \sum a_i T^i, \tag{3}$$

where i runs from 0 to 2.

The regression will also generate the standard errors of estimate, s. There will be a different value of s for each detector. These will be used as described in the next section.

The regression will be performed at every blackbody sequence and will be done separately for each detector.

The dependent sample of data for the regression will be obtained from the existing SPS 10-day history file. This file contains slopes and optics temperatures sampled once every blackbody sequence (usually once every 30 minutes). The slopes in this file are those computed by the technique described at the beginning of this section, i.e., a quadratic calibration modified to account for the polarization-induced change of the scan mirror's reflectivity with east-west scan angle. However, these slopes are not filtered to reduce noise, i.e., they are computed in mode 1, not mode 3, and so they are represented by m_1. The optics temperatures in this file are two-minute averages. An operator is able to select as the predictor the temperature of any one of the available optics temperatures, which include those of the scan mirror, primary mirror, secondary mirror (2), baffle (2), aft (visible) optics, electronics, etc. Our development work indicates that the primary temperature appears to be the best choice. The predictand will be the mode-1 responsivity r_1, which in the dependent sample will be calculated from m_1 for the particular detector by Eq. (2).

The dependent sample will exclude data from the period from midnight minus H1 hours to midnight plus H2 hours, because the slopes in that period may be erroneous. H1 and H2 are operator selected parameters.

The regression will be performed with data from the current day and the previous ND days, where ND is an integer that can take any value from 0 to10.

The optics temperature and responsivities in the regression will be quality controlled. Optics temperatures outside a specified range of temperatures will be eliminated. The upper and lower temperature thresholds for the predictor optics temperature will be the limits provided in the factory database. Before doing the regression, the SPS will compute the mean μ and standard deviation σ of all the responsivities in the dependent sample. The method for screening the responsivities will be to reject from the dependent sample all responsivities whose values are not between μ - Mσ and μ + Mσ, where the factor M is an operator-selected integer.

2. Slope Computation

At each blackbody sequence, the slope will be computed as usual, including correction for the polarization-induced change of the scan mirror's reflectivity with east-west scan angle, and, if currently operational, the filtering to reduce noise (mode 3). This is the original slope. At the same time, however, the SPS will also use the unfiltered slope m_1 (computed in mode 1) to compute the original mode-1 responsivity r_1 by Eq. (2).

At each blackbody sequence, after the regression coefficients have been determined as described above, the estimated mode-1 responsivity r_1^{est} will also be generated from Eq. (3).

For each detector, the difference $r_1^{est} - r_1$ will then be formed. If this difference is less than or equal to Ns, where s is the standard error of estimate of the responsivity (see discussion following Eq. [3]), and N is an operator-selectable integer (a separate value for each channel), then the original slope will be used in further processing. If the difference is greater than Ns, then the slope associated with the estimated mode-1 responsivity will be computed as

$$m_1^{est} = (1/r_1^{est}) - 2qX_{bb} .$$

This slope will be used in all further processing until the next calibration. If mode 1 is the operational calibration mode, then m_1^{est} itself will become the operational slope. If mode 3 is operational, then m_1^{est} will be filtered before being used.

The midnight algorithm cannot be used until L days have elapsed after an instrument is first turned on and after a patch-temperature change, where L is an operator selected parameter. Otherwise, the dependent data sample in the 10-day file will not be representative of current conditions.

For each detector, a flag indicating whether the midnight algorithm is active or not at each blackbody sequence will be included in the SPS 10-day history file. However, these flags will not be transmitted in GVAR, stored in the RPM short-term blackbody history file, or printed out with the contents of that file in response to the PRINT SHORT BBCAL command.

III REFERENCES

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Weinreb, M.P., M. Jamieson, N. Fulton, Y. Chen, J.X. Johnson, C. Smith, J. Bremer, and J. Baucom, 1997: Operational Calibration of GOES-8 and -9 Imagers and Sounders. *Applied Optics,* **36**, 6895-6904.